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9. INTEGRATIVE SYNTHESIS

9.1 INTRODUCTION

- This chapter synthesizes information presented in Chapters 2 through 8 of this PM Air Quality Criteria Document (PM AQCD) by addressing several key questions that will inform the Agency's review of the primary and secondary PM NAAQS. As such, it is not intended as a stand-alone summary of the information presented in the earlier chapters, and it does not duplicate much of the key information contained in those chapters.

- In synthesizing the PM-related health and welfare effects information, this chapter will focus on integrating newly-available scientific information with the information available in the last review. In particular, in considering the PM-related health effects information, this chapter will build upon the integrative synthesis presented in the Chapter 13 of the 1996 PM AQCD.

- The goal of the chapter is to present updated syntheses of scientific information in a manner that will facilitate consideration of the key policy-related NAAQS issues to be addressed in the PM Staff Paper, prepared by staff in EPA's Office of Air Quality Planning and Standards. These policy-related issues include consideration of the appropriate indicators, averaging times, forms, and levels for PM standards in the U.S.. Consideration of these issues will be informed not only by the information contained in this chapter and throughout this criteria document, but also by additional policy assessments of scientific and technical information to be included in the PM Staff Paper.

- While this synthesis focuses on what has been learned from the new information that has become available since the last PM NAAQS review, it also highlights important uncertainties that remain and recognizes the value of continuing research in a number of key areas. Although the development of research recommendations in these areas is beyond the scope of this document, such recommendations are to be addressed in other PM research needs documents to be prepared by EPA and other organizations such as the NAS.

9.2 SYNTHESIS OF AVAILABLE INFORMATION ON PM-RELATED HEALTH EFFECTS

9.2.1 Does the newly-available information continue to support consideration of fine and coarse particles as separate subclasses of PM pollution?

9.2.1.1 Key Points from 1996 Integrative Synthesis

- The evidence indicates that "it would be appropriate to consider fine and coarse mode particles as separate subclasses" of PM pollution. This conclusion was based on differences between fine- and coarse-mode particles related to their chemical and physical

properties, evidence suggestive of different biological effects, and their derivation from different sources. (U.S. EPA, 1996, p. 13-91 through 13-94)

9.2.1.2 Integration of New Information

- Information on emission sources, formation mechanisms, atmospheric transformation, transport distances, composition, air quality patterns, and exposure relationships for fine and coarse mode particles

- Dosimetry studies on deposition and clearance patterns, including in particular comparisons between accumulation mode particles and coarse and ultrafine particles

- Toxicological studies on fine and coarse particles and their components

- Epidemiological studies, including the number of newly-available studies looking at fine and coarse particle effects

9.2.2 How does the newly-available information inform our judgments about the strength of the evidence for health effects related to ambient PM acting alone and in combination with other pollutants?

9.2.2.1 Key Points from 1996 Integrative Synthesis

- "The evidence for PM-related effects from epidemiologic studies is fairly strong, with most studies showing increases in mortality, hospital admissions, respiratory symptoms, and pulmonary function decrements associated with several PM indices. These epidemiologic findings cannot be wholly attributed to inappropriate or incorrect statistical methods, misspecification of concentration-effect models, biases in study design or implementation, measurement errors in health endpoint, pollution exposure, weather, or other variables, nor confounding of PM effects with effects of other factors. While the results of the epidemiology studies should be interpreted cautiously, they nonetheless provide ample reason to be concerned that there are detectable human health effects attributable to PM at levels below the current NAAQS." (U.S. EPA, 1996, p. 13-92)

- While epidemiological studies indicate increased health risks associated with exposure to PM, alone or in combination with other air pollutants, the role of PM as an independent causal factor has "not [been] completely resolved" based on the available studies using multiple air pollutants as predictors of health effects (U.S. EPA, 1996, p. 13-92).

9.2.2.2 Integration of New Information

- Consideration of the validity and coherence of evidence from studies world-wide

- Extensive new epidemiological evidence, including:

  - Information related to model selection/specification, with special focus on the reanalyses results and associated HEI review
  - Information on potential influences of co-pollutants, including multi-pollutant model results (e.g., NMMAPS), other approaches to evaluate co-pollutant confounding, and the results from single pollutant models in areas with different mixes of co-pollutants
  - Intervention studies
  - Consideration of the consistency and coherence of the epidemiological evidence

- Toxicological evidence related to evaluating the plausibility of PM effects and understanding potential mechanisms; including CAPs studies in particular

- Exposure-related information on PM and other gaseous pollutants (O_3, CO, etc.).

- Information related to biological plausibility of PM and the gaseous pollutants for respiratory- and cardiac-related effects

9.2.3 How does the newly-available evidence inform our understanding of the effects of fine and coarse particles and their major components?

9.2.3.1 Key Points from 1996 Integrative Synthesis

- The PM indices that have been "most consistently associated with health endpoints are fine particles (indexed by BS, COH, and $PM_{2.5}$), inhalable particles (PM_{10} or PM_{15}), and sulfate ($SO_4^{=}$)," whereas "[l]ess consistent relationships have been observed for TSP, strong acidity (H^+), and coarse PM ($PM_{10-2.5}$). . . . [and] none of these indices can completely be ruled out as a biologically relevant indicator of PM exposure."

- "The likelihood of ambient fine mode particles being significant contributors to PM-related mortality and morbidity among [the] elderly population is bolstered by: (1) the more uniform distribution of fine particles across urban areas . . . ; (2) the penetration of ambient particles to indoor environments . . . ; and (3) the longer residence time of ambient fine particles in indoor air, enhancing the probability of indoor exposure to ambient fine particles more so than for indoor exposure to ambient coarse particles."

- "Based on current evidence from epidemiologic, controlled human, human occupational, and laboratory animal studies, no conclusions can be reached regarding the specific chemical components of PM_{10} that may have the strongest biologic activity." Further, none of the various subclasses of PM [e.g., acid aerosols, bioaerosols, metals (including transition metals), and insoluble ultrafine particles] that have been considered "can be specifically implicated as the sole or even primary cause of specific morbidity and mortality effects." (U.S. EPA, 1996, p. 13-93)

9.2.3.2 Integration of New Evidence

- Focus on quantitative results from U.S. and Canadian epidemiological studies (with tables of study results, currently summarized in Tables 9-8, 9-10, and 9-11 in the June 2003 4th draft PM AQCD, to be moved to an Appendix)
  - Studies of $PM_{2.5}$ vs. $PM_{10-2.5}$ and fine and coarse components
  - Studies of PM_{10} in predominantly fine particle areas, as well as those in predominantly coarse particle areas
  - Factor analysis studies

- Toxicological evidence related to understanding potential mechanisms of fine and coarse particles and their major components

- Consistency and coherence of exposure, toxicological, and epidemiological evidence related to short-term (e.g., hours, days) and long-term exposures to fine particles, coarse particles, and their major components

9.2.4 How does the newly-available information inform our understanding of the subpopulations potentially susceptible to PM-related health effects?

9.2.4.1 Key Points from 1996 Integrative Synthesis

- "There is considerable agreement among different studies that the elderly are particularly susceptible to effects from both short-term and long-term exposures to PM, especially if they have underlying respiratory or cardiac disease. . . . Children, especially those with respiratory diseases, may also be susceptible to pulmonary function decrements associated with exposure to PM or acid aerosols." (U.S. EPA, 1996, p. 13-92)

9.2.4.2 Integration of New Information

- Information on pre-existing disease as risk factors (e.g., new evidence on diabetes)

- Information on age-related risk factors (e.g., new evidence on neonatal and infant effects)

9.2.5 What does the newly-available information imply with regard to potential public health impacts of human exposures to ambient PM in the U.S.?

9.2.5.1 Key Points from 1996 Integrative Synthesis

- "Efforts to quantify the number of deaths attributable to, and the years of life lost to, ambient PM exposure are currently subject to much uncertainty." (U.S. EPA, 1996, p. 13-87) Nonetheless, while "PM-related increases in individual health risks are small," they are "likely significant from an overall public health perspective because of the large

numbers of individuals in susceptible risk groups that are exposed to ambient PM." (U.S. EPA, 1996, p. 1-21)

9.2.5.2 Integration of New Information

- New studies on harvesting and life-shortening
- C-R functions and consideration of thresholds
- Studies on distributed lags and persistence of effects
- Comparative risks from short-term vs. long-term studies
- New evidence on children and infants
- New observed endpoints (e.g., doctor's visits), adding to pyramid of effects associated with exposure to ambient PM

9.3 SYNTHESIS OF AVAILABLE INFORMATION ON PM-RELATED WELFARE EFFECTS

- Since PM-related vegetation and ecosystem effects were not addressed in the 1996 PM AQCD, the discussion below will be drawn entirely from the information presented in Chapter 4, section 4.2 of the 2003 PM AQCD.
- Discussion of the other welfare effects below will reflect that there is generally only limited new information available in these areas relevant to an evaluation of effects related to ambient PM.

9.3.1 What does the available information indicate about the direct and indirect effects on vegetation and natural ecosystem integrity of ambient PM and its major constituents?

9.3.2 What does the available information indicate about the effects on visibility associated with ambient PM and its major constituents?

9.3.2.1 Key Points from 1996 PM AQCD

- "The relationships between air quality and visibility are well understood. Ambient fine particles are the major cause of visibility impairment. Significant evidence exists showing that reducing fine particle concentrations will improve visibility." However, visibility effects "are dependent upon not just the mass of pollutants, but on the size distribution and refractive index of particles, which are strongly influenced by relative humidity." (U.S. EPA, 1996, p. 1-18)

9.3.2.2 Integration of New Information

9.3.3 What does the available information indicate about the effects on man-made materials associated with ambient PM and its major constituents?

9.3.3.1 Key Points from 1996 PM AQCD

- "Particle exposure results in the soiling of painted surfaces and other building materials, increasing the cleaning frequency for exposed surfaces and possibly reducing their useful lifetimes." (U.S. EPA, 1996, p. 1-19) Damage to materials can result from the deposition of acid aerosols and the dissolution of acid forming gases on metal surfaces, increasing the corrosion of metals; "exposure to acid forming gases may also limit the life expectancy of paints and may damage various building stones and cement products beyond that resulting from natural weathering processes." (U.S. EPA, 1996, p. 1-20)

9.3.3.2 Integration of New Information

9.3.4 What does the available information indicate about the relationships between atmospheric PM and climate change processes?

9.3.4.1 Key Points from 1996 PM AQCD

- "Particles [primarily fine particles] suspended in the atmosphere affect the earth's energy budget and thus exert an impact on climate: (a) directly by increasing the reflection of solar radiation by cloud-free portions of the atmosphere, and (b) indirectly by affecting cloud microphysical properties in ways that increase the brightness and stability of clouds." Since aerosol lifetimes are much shorter than the time required for global mixing, "aerosol radiative effects are most likely to exert their influence on a regional rather than on a global basis." (U.S. EPA, 1996, p. 1-19, 1-21)

9.3.4.2 Integration of New Information